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ABSTRACT

Most students enter their first formal science courses with intelligently conceived and sophisticated concepts of science. Some of these may be compatible with the principles of modern science, but others may be incorrect, inadequate, outdated, or otherwise unacceptable. Conceptual frameworks based on intuitive misperceptions, naive inferences, incorrect logic, or misinformation constitute a threat to further science education. Many studies have found evidence of widespread scientific misperceptions among young children, high school and college students, college graduates, and even science teachers. Examples, include ideas about the relation of force and motion similar to medieval or Aristotelian theories, and outdated concepts of time, space, and photosynthesis. Some misconceptions are so intuitively satisfying and so ingrained that they are not easily displaced by later science instruction. Diagnostic techniques and skills can enable teachers to identify their own misconceptions and help students articulate and unlearn scientific preconceptions without undermining their intellectual self-confidence and receptivity to science learning. Many rural and small schools do not have the resources to deal with this problem. Some simple experiential techniques to help students articulate what they believe about natural phenomena include the "Tennessee Teaching Machine" (force and motion), "World on a String" (space), and "Plant Diet" (photosynthesis). A rationale for a constructivist approach to science instruction is presented, based on theories of Piaget and Ausubel. This paper contains 20 references. (SV)

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TECHNIQUES FOR PROMOTING INTELLECTUAL SELF CONFIDENCE AMONG AT-RISK SCIENCE STUDENTS IN RURAL AND SMALL SCHOOLS

Introduction

Children are naturally inquisitive learners, and rural environments may be especially stimulating arenas for early learning experiences related to a diversity of natural phenomena. As a result, most students, including those at the elementary school level, enter their first formal science study with many intelligently conceived and quite sophisticated concepts of science. Some of these may be compatible with the principles of modern science and some may be incorrect, inadequate, outdated, or otherwise unacceptable in a science oriented culture (Ault, 1984; Clement, 1982; Kuethe, 1963). Clement (1982), DiSessa (1982), Driver (1983), and others reported that common misperceptions of several basic concepts of physical science are widespread.

Reporting on a review of more that 100 studies involving approximately 23,000 subjects on five continents, Wandersee, Mintzes, and Arnaudin (1987) presented evidence of widespread development of misperceptions of basic biological phenomena during childhood. Carey (1987) reported similar evidence of biological preconceptions among very young children as well as adults. Mintzes (1989) cited several common misperceptions that are persistent problems for biology teachers.

Concepts based on sound science information constitute a basis for further science education. Conceptual frameworks based on intuitive misperceptions, naive inferences, incorrect logic, and/or misinformation constitute a threat to further science education. Research in cognitive psychology and science education has indicated that some common misconceptions are not displaced by subsequent science instruction (Caramazza, McCloskey, and Green, 1981; Champagne, Klopfer, and Anderson, 1980; Clement, 1982; Driver, 1983; McCloskey and Kohl, 1983). Several studies indicated that most adults who studied physics in high school and college continue to hold preconceived intuitive concepts of the relation of force and motion similar to the medieval theory of Impetus, which is inconsistent with the principles of Newtonian mechanics (Kuethe, 1963; McCloskey, 1983, 1984). Many students also continue to hold outdated concepts of time (Ault, 1984), photosynthesis (Wandersee, 1986), or other natural phenomena.

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"For the person who holds it, a misperception feels like the truth--he doesn't know that he doesn't know" (Eaton, Anderson, and Smith, 1983, p. 7). Some common misconceptions may be so intuitively satisfying and become so ingrained over time until they are not displaced by subsequent science instruction. For example, studies in cognitive psychology indicated that the majority of school and college science students continue to hold preconceived intuitive concepts of the relation of force and motion similar to the medieval theory of Impetus (Clement, 1982) or ancient Aristotlean concepts of motion (DiSessa, 1982), which are inconsistent with the principles of Newtonian physics. From this it is evident that teachers cannot assume that students will recognize and replace the common misconceptions of science in the course of formal science instruction. Consequently, scientific misperceptions constitute a serious impediment to science education for the majority of students.

Scientific misperceptions also may be a critical consideration for science education students preparing for teaching careers. For instance, a scientific misconception that may have prevailed through a teacher's school and college science instruction could adversely affect subsequent science teaching performance. Diagnostic techniques are needed to enable preservice and inservice teachers to identify and correct any of the common misperceptions that may have prevailed through their science preparation.

Teachers also need diagnostic techniques and skills for dealing with students' scientific misperceptions in a way that will help the students articulate and unlearn inadequate preconceptions in a way that will not undermine the students' intellectual self-confidence or otherwise alienate their natural receptivity to science learning. Limited budgetary resources, small science staffs, and crowded curricula in many rural and small schools preclude the equipment, faculty resources, and class time that would be required to deal with this problem through traditional instructional means.

The Techniques Employed in the Presentation

This program presented several "hands-on/minds-on science" techniques for helping students articulate what they may believe about natural phenomena such as the relation of force and motion, photosynthesis, and space. One of these, the "Tennessee Teaching Machine," is a simple device that may be used to help people of all ages or educational backgrounds discover what they believe, as compared to what they may know, about the relationships of force and motion as reflected in Newton's First Law. The method appears to be totally independent of either writing or mathematical skills and therefore appropriate for measuring science understanding.

Another activity, the "World-On-A-String," is designed to help students develop a scientifically adequate concept of matter in space and learn the worth of mathematics while studying the solar system. An activity on "Plant Diet" is designed to help students articulate what they really believe about photosynthesis while learning basic process skills and experimental methodology.

In cases where misperceptions are revealed, the above techniques are useful to help students unlearn their preconceptions and replace them with more adequate scientific concepts in a non-threatening environment supportive of Piagetian and Ausubelian learning theory. Perhaps most important of all, the learning is experienced in a manner that may promote appreciation of science and maintain the students' intellectual self-respect.

The limited space allowed for this article precluded inclusion of specific information about the techniques demonstrated. For example, the explanation of the "World-On-A-String," a common-sense idea that may be grasped in a moment through hands-on experience, required a minimum of five pages of text, plus illustrations. The author will attempt to provide information about specific techniques upon request.

The Presentation

The purpose of this program was to share ideas about ways that science teachers might help students recognize and unlearn erroneous notions about science and replace them with sound new science concepts without lessening students' intellectual self-confidence or alienating their receptivity to further science learning.

The presentation consisted of a brief explanation of the nature of the problem of scientific misperceptions and a discussion of research on the topic, with emphasis on the implications for rural education as discussed by Hollos (1987) and others. Four "hands-on, minds-on-science" activities were demonstrated, with emphasis on how the activities may be used to help students examine their science beliefs in a discrete manner and unlearn them if necessary as an essential first-step to effective science education. Suggestions for incorporating the teaching techniques into existing school curricula were provided during discussions with conference participants.

Justification of the Instructional Concept

When an inadequate scientific notion has supplied an apparently satisfactory explanation of a student's experiences over an extended period of time, Clement (1982) noted, a more adequate concept encountered in formal science instruction may be simply disregarded or "more likely . . . misperceived or distorted by students so as to fit their existing preconceptions" (p. 70).

Consequently, teachers cannot simply assume that erroneous preconceptions of science will be recognized by students and replaced by correct science information in the course of formal science instruction.

It is clearly in the interest of science education to help students quickly recognize the inadequacy of incorrect perceptions of science they may hold and replace them with concepts that are consistent with modern science. This may not be a simple matter because many persons holding such perceptions are "intelligently wrong" (Ault, 1984, p. 22). Their ideas may be based on purposful observations, careful thought, reasonable interpretations of meaningful experiences, and/or authoritative non-science sources of information. Consequently, it is important that efforts to help students recognize and unlearn inadequate preconceptions not undermine their intellectual self-confidence or otherwise alienate their receptivity to further science learning. Considering the reports of serious declines in public confidence and appreciation of science over the past two decades, this attitudinal factor could be a critical influence on the future of both science and science education in the United States.

A review of literature revealed reports of studies on the problem of alternative conceptual frameworks related to virtually every science-related field and spanning the full spectrum of education from kindergarten through college in many countries. Za'rour (1976), in a study involving 220 Lebanese Arab students ranging from kindergarten to fourth grade, reported common misperceptions in the area of chemistry, physics, earth science and biology. Ault (1984), DiSessa (1982), Driver (1983), and Eaton et al. (1983) observed naive preconceptions among elementary and middle school students on a diversity of topics including astronomical phenomena, biological growth and adaptation, molecular theory, composition of air and atmospheric pressure, energy, electromagnetic theory, time and space, gravity, and the relation of force and motion. Kuethe (1963), McCloskey (1983), and Viennot (1979) reported similar problems among hundreds of high school seniors and college students, especially with regard to concepts of force and motion, thermodynamics, and astronomy.

From a review of studies involving students from Canada, Germany, Israel, Lebanon, Norway, Scotland, Sweden and the United States, Driver(1983) concluded that "the general picture that emerges is of a considerable number of secondary pupils holding on to certain intuitive notions despite the science training they receive in school" (p. 30). Other research revealed similar retention of naive preconceptions among college students and adults. For example, McCloskey (1983) reported that "although Newton's Laws are well known . . . many people believe that moving objects behave otherwise" (p. 122). Clement (1982), reporting on a study of freshmen engineering majors prior to their introductory col-

lege physics course (most had studied high-school physics), noted that the majority (88 percent in one case) of students attempted to explain acceleration in non-Newtonian terms.

Many earlier studies of the problem of inadequate preconceptions in science focused on the cataloging of common misperceptions. These studies have helped to point out the problem areas, Driver concluded, but some have also given the impression that the sources of erroneous perceptions are simply mislearned facts. Some misperceptions may be of this nature, she concluded; and these could be easily corrected by the teaching of new, correct facts. However, Driver argued, there is a preponderance of evidence that the problem is not nearly so trivial nor its solution so superficial: "In many cases the source of particular errors derives from pupils having very different models or alternate frameworks from those of the scientific community" (Driver, 1983, p. 26). These alternative frameworks, she added, cannot be disregarded in science education. McCloskey (1984) concurred on the basis that many students who hold incorrect alternative concepts appear to interpret new course materials within that erroneous framework.

DiSessa concluded that it is unrealistic to assume that erroneous concepts will disappear and be replaced by correct information in the routine course of science instruction. About 50 percent of students, even at the university level, approach many problems of force and motion from a non-Newtonian perspective very similar to Aristotelian physics, DiSessa found; and in most cases this outdated frame of reference appeared to provide fully satisfactory explanations of numerous experiences during the students' lifetimes. McClosky (1984) cited a widespread occurrance of outdated medieval notions of science that "persist today, perhaps because they seem to explain, simply, much of what we observe about motion in everyday life" (p. 55). Eaton et al. (1983) reported deep-seated misperceptions of the nature of light that prevented many students from learning its correct role in photosynthesis: "Most students never made the connection between light and food making; they had explained the phenomenon to their own satisfaction without it" (p. 8).

Research by Clement (1982) revealed a prevalence of pre-Newtonian concepts of motion among three groups of college science majors. Some inadequate notions, he noted, "appear to originate in intuitive preconceptions that the student develops on his own before entering [science] courses" (p. 66). Driver cited evidence that children at a very early age construct such preconceptions about natural phenomena, in an effort to make sense of everyday experiences. McCloskey (1984) cited similar evidence of sophisticated conceptual frameworks that four-year olds developed to explain their observations of objects in motion. Ault (1984) reported similarly conceived misperceptions of the nature of both time and mathematics among groups of first-grade students. Consequently,

as Clement observed, teachers cannot assume a student's mind to be a "blank slate" in the area of science prior to their first science instruction.

As indicated earlier, several studies reported that many well-educated adults have retained erroneous intuitive notions about objects in motion despite formal study in high school and college science. Clement reported that, even after two semesters of college physics, 70 percent of the subjects in one test group of engineering majors still attempted to explain the mechanics of a coin-toss in terms of the outdated concept that motion implies force. Boyd (1966) reported no direct relationship between the number of science courses taken and the ability to correctly identify unfounded beliefs about science. Consequently, Clement (1982) concluded, certain deep-seated misperceptions of natural phenomena, especially those that have provided satisfactory explanations of student observations over long periods of time, are not likely to disappear simply because student encounter new, more scientifically correct concepts in science courses.

The research also indicated that basic errors regarding the nature of force and motion are among the most prevalent and persistent misconceptions (Clement, 1982; Disessa, 1982; McCloskey and Kohl, 1983). Considering the fundamental role of Newtonian physics in all aspects of modern science, this bespeaks a critical situation for science education. Additional research is needed to establish the full educational import of this issue, but it seems clear that common scientific misconceptions relating to the basic elements of Newtonian physics constitute a critical challenge to science education for many, perhaps the majority of, students.

Research has also indicated that successful science education will require more than an opportunity for students to refute their misperceptions through exposure to superior scientific concepts in the course of their science studies. A synthesis of the concerns of Clement, DiSessa, Driver, McCloskey, and others further indicated that successful science education will require new teaching strategies. Such strategies should ensure that basic misperceptions are recognized and their inadequacies realized, and that they are unlearned and replaced by superior concepts that are compatible with the principles of modern science.

Several writers made suggestions regarding teaching strategies. One group recommended that science teachers work together to develop discussion and questioning techniques that would identify student misperceptions and that they select curricular materials that "explicitly contrast these misconceptions with scientific explanations" (Eaton et al., 1983, p. 8). Once a misperception has been identified, they added, teachers should contrast it to the currently accepted scientific concept to show how and why the

latter is superior. The student would then be ready for instruction on the appropriate alternative. The "Tennessee Teaching Machine" was demonstrated as an effective means to accomplish this.

Driver suggested a similar approach and recommended Harvard Project Physics (1970, Holt and Rinehart) as a curricular resource. She also strongly recommended the identification and correction of naive conceptual frameworks in the earliest stages of science education to minimize the residual effect of erroneous preconceptions on the interpretation of subsequent observations. The "World-On-A-String" was demonstrated as an effective means to help elementary students dispel possible textbook-induced misperceptions about interstellar space.

Clement (1982) declared that teachers should develop strategies that would "encourage students to articulate and become conscious of their own preconceptions by making predictions based on them" (p. 70). For example, Newton's First Law prescribes that a body in motion tends to remain in constant, straight-line motion unless acted upon by a resultant force; but Clement found that a majority of the engineering majors tested applied "the idea that continuing motion implies the presence of a continuing force" (p. 67). He advocated having students conduct experiments to compare the predictive efficacy of their preconceptions with that of accepted scientific explanations. The "Tennessee Teaching Machine" was demonstrated as a means to accomplish this.

Some misconceptions are so intuitively attractive and convincing, Clement (1982) indicated, that, when the correct concepts are encountered in the classroom or laboratory, they are commonly misperceived or distorted to fit the preconception. "In such cases learning becomes a process in which new concepts must displace or be remolded from stable concepts that the student has constructed over many years" (p. 66). The first step in that process, he declared, is helping students articulate their preconceptions so they may become conscious of the inadequacies of any misconceptions they may hold. Then, he implied, other alternatives, when presented through conventional instructional means, may be perceived as meaningful new concepts to be learned rather than as confusing and/or irrelevant ideas that appear to conflict with students' observations of the world around them. The "Plant Diet" exercise was demonstrated as an example of a means of accomplishing this.

DiSessa (1982) described a set of computerized laboratory exercises designed to help students recognize and unlearn erroneous preconceptions of force and motion and obtain an operational understanding of Newton's laws. Like Clement, she believed that an understanding of students' preconceptions about science may be critical to the success of the teaching effort. Otherwise, some of the more entrenched preconceptions may outweigh "the perturba-

tions we can apply as teachers" (p. 65). Like Disessa, Driver (1983) argued that science teaching must begin at the level of students' preconceptions:

Driver attributed much of science education's failure to dispel scientific misconceptions to "The Fallacy of Inductive Science Teaching" (Driver, 1983, p. 1). By the time children reach their first science class, they already have many well-developed, but perhaps naive, conceptual frameworks with which they interpret natural phenomena. Consequently, interpretations of the same data may vary greatly among students, depending upon the preconceptions they bring into the classroom or laboratory. That possibility of multiple interpretations of data, she concluded, constitutes a serious problem in inductive science teaching.

A constructivist point of view was promoted by most of the writers noted above. Driver, for example, contended that many of the principles of modern science do not spring clearly from data. Relationships that are immediately obvious to a trained scientist may be quite obscure to students in a laboratory class, she argued; and teachers cannot depend upon the basic theoretical models and conventions of science being discovered in the course of practical experiences, in the classroom or elsewhere. Most of them, she concluded, are simply not that obvious. Guidance may be necessary for many students to make the conceptual leap that may be required to comprehend their experiences in terms of conventional scientific concepts. Otherwise, scientific information encountered in a lesson may either confuse them or inadvertantly reinforce an erroneous preconception. "Not only do children have to comprehend the new model or principle being presented to them, but they have to make the intellectual leap of possibly abandoning an alternative framework which until that time had worked well for them" (Driver, 1983, p. 9)

The constructivists' point of view may be philosophically justified on the revolutionary science historiography of Kuhn (1970) and others who advocated the paradigmatic concept of scientific development. Driver's position was also convincingly grounded in the psychological concepts of two major educational theories: Piaget's theory of cognition and Ausubel's theory of meaningful learning.

In Piagetian terms, learning occurs, within the limits of cognitive development, as new cognitive structures are formed by the assimulation of new information sufficient to resolve disequilibrium resulting from conflict between a student's observations and individual expectations. If the dissonance created by novel experiences is either too little to motivate assimilation or too great to accommodate through cognitive restructure, learning will not occur. Ausubel contended that learning occurs only when the new information is sufficiently meaningful to be relevant to what the learner already knows or wants to know.

The "Tennessee Teaching Machine," like the other techniques demonstrated during this presentation, enables the student to make predictions, experiment to see if nature behaves as predicted, and retest as many times as needed to confirm the results. In cases where a mispercetion may be revealed, the student is immediately introduced to "Newton's Laws" and encouraged to make and test predictions using Newton's ideas. Through simple activities, students may also examine other concepts such as gravity and acceleration. In each case where a misperception is encountered, the technique creates a cognitive disequilibrium (realization that nature doesn't work as the student predicted), and the student is able to test a more adequate concept. If the student realizes the superiority of the alternate concept, this becomes meaningful learning in the fullest sense of the term.

In no case should a student be graded or in any sense penalized for revealing misperceptions in learning experiences of this nature. Rather, techniques such as the "Tennessee Teaching Machine" provide students an opportunity to articulate and quickly unlearn prior misconceptions that may preclude further science understanding. From the Ausubelian perspective, once a student is confident of the superiority of the new concept, the examination of other preconceptions in like manner may be perceived as meaningful learning activities to be pursued. "Seeing is believing" is a common and reasonable reaction among most inquisitive observers, and hands-on-science teaching methods provide students an opportunity to test the basic principles of science and see the results for themselves.

The affective benefits are obvious. Accommodation of new science information in this manner should bolster rather than undermine students' intellectual self-confidence and interest in science; consequently, this sort of learning experience should accomplish several very important goals of science education. For instance, it may produce new science learning through the correction of erroneous preconceptions, while simultaneously creating an acute awareness of the nature and goals of the scientific enterprise. Attitudinally, it may create an awareness of the worth of science study while simultaneously enhancing students' self-confidence regarding their capacity for self-initiated scientific thinking. It should also help to demonstrate the tentative nature of scientific knowledge in a way students can clearly understand and appreciate. The result, quite likely, will be a highly motivated science learner.

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